

REMARKS

This Preliminary Amendment cancels original claims 1 to 15 in the underlying PCT Application No. PCT/DE03/01809 and adds new claims 16 to 30. The new claims conform the claims to the U.S. Patent and Trademark Office rules and do not add new matter to the application.

In accordance with 37 C.F.R. § 1.125, the Substitute Specification (including the Abstract, but without the claims) contains no new matter. The amendments reflected in the Substitute Specification (including the Title and Abstract) are to conform the Specification and Abstract to U.S. Patent and Trademark Office rules or to correct informalities. As required by 37 C.F.R. § 1.121 and § 1.125, a Marked Up Version Of The Substitute Specification comparing the Specification of record and the Substitute Specification also accompanies this Preliminary Amendment. In the Marked Up Version, underlining indicates added text and "strike-throughs" and double-brackets indicate deleted text. Approval and entry of the Substitute Specification (including Abstract) are respectfully requested.

Also enclosed is a translated copy of the International Search Report dated November 17, 2003. The Search Report includes a list of documents that were considered by the Examiner in the underlying PCT application.

It is asserted that the subject matter of the present application is new, non-obvious, and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully Submitted,
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SEMICONDUCTOR SYSTEM AND METHOD OF MANUFACTURE

~~Background Information~~ FIELD OF THE INVENTION

The present invention relates to a semiconductor system
according to the definition of the species in Claims 1, 12, 13
as well as a method for manufacturing it according to the
5 definition of the species in Claim 14. .

BACKGROUND INFORMATION

~~DE 4320780 A1 describes~~ German Patent Document No. 43 20 780
refers to a semiconductor diode, in which the doping profile
at the edges of the diode deviates from the doping profile at
10 the center. This can be used so that in reverse-biased
operation the voltage breakdown, which sets in at breakdown
voltage U_Z , occurs only in the central part of the diode and
not at the edge. This results in a high robustness in
operation since no avalanche breakdown can occur at the chip
15 edges.

~~DE~~ German Patent Document No. 43 20 780 A1 further
~~describes~~ refers to a semiconductor system having a p-n
junction, in particular a diode, which takes the form of a
chip having an edge region, which is constructed of a first
20 layer of a first conductivity type and a second layer of the
opposite conductivity type, the second layer being made up of
at least two sublayers. In this instance, the first sublayer
has a first dopant concentration, while the second sublayer
has a second dopant concentration which is lower than the

first dopant concentration. Together with the first layer, both sublayers form a p-n junction, the p-n junction of the first layer with the first sublayer being formed exclusively in the interior of the chip and the p-n junction between the first layer and the second sublayer being formed in the edge region of the chip.

~~Summary of the Invention~~

The ~~known~~available semiconductor system has the distinction of having a high robustness in operation since, due to the special form of the doping profile in the edge region, no voltage breakdown occurs in the edge region in reverse-biased operation of the semiconductor system. It is disadvantageous, however, that ~~the known~~this semiconductor system has a relatively high electrical resistance as a result of its lightly doped middle layer. This high electrical resistance causes an undesired voltage drop, which has an adverse effect particularly in breakdown operation. This is all the more pronounced the higher the breakdown voltage U_Z of the semiconductor system. For this reason, ~~the known~~this semiconductor system is not suited for higher breakdown voltages, as required, for example, for use in a 42 volt vehicle electrical system.

SUMMARY OF THE INVENTION

The semiconductor system according to the present invention avoids this disadvantage due to its special layer structure. Hence it is excellently suited for use in vehicle electrical systems that operate at a voltage higher than 24 volts.

Furthermore, the semiconductor system according to the present invention is characterized by a lower reverse current, a more robust behavior in the event of temperature changes as well as a higher pulse strength. The lower reverse current and the higher pulse strength are due to the fact that, in the

semiconductor system according to the present invention, the space charge region at the edge region of semiconductor system 10 extends further than in its central region, thereby lowering the electric field strength at the surface of the edge region. As a consequence of the low reverse currents, it is also possible to dispense with a removal of the damage zone, for example by etching.

~~Brief Description of the Drawing~~

~~Exemplary embodiments of the present invention are depicted in the drawings and will be explained in greater detail in the following description. The figures show:~~

BRIEF DESCRIPTION OF THE DRAWINGS

~~Fig. 1~~ Figure 1 shows a known semiconductor system in a schematic sectional view~~Fig.~~

15 ~~Fig. 2~~ Figure 2 shows a first exemplary embodiment of a semiconductor system according to the present invention in a schematic sectional view~~Fig.~~

~~Fig. 3~~ Figure 3 shows a second exemplary embodiment of a semiconductor system according to the present invention~~Fig.~~

20 ~~Fig. 4 (Fig. 4a, Fig. 4b)~~ Figure 4a shows a comparison of the saw trench geometry between a known semiconductor system~~(Fig. 4a)~~

~~andb shows~~ a semiconductor system according to the present invention ~~(Figure 4b)~~ in detail in a sectional view~~Fig.~~

25 Figure 5 shows a diagram of the schematic representation of the doping profiles of the known semiconductor system and of the semiconductor system according to the present invention in comparison along section AB~~Fig.~~

Figure 6 shows a further exemplary embodiment of the present invention, in which contiguous layers of the semiconductor system are made of the same doping type.

~~Description of the Exemplary Embodiments~~

5 DETAILED DESCRIPTION

Figure 1 first shows a known semiconductor system 10 made up of several variably doped layers 1, 2, 3, 4. Layers 1, 2, 4 are n-doped at different concentrations, while layer 3 is a p-doped layer. The outer surfaces of layers 3 and 4 are coated with contact layers 5, 6 made of metal. This semiconductor system 10 is a diode for example. Together with the n-doped layers 1, 2, p-doped layer 3 forms a p-n junction. Since higher n-doped layer 2 is essentially found only at the center of the semiconductor system, the doping profile at the edges of the diode differs from the doping profile in the central region of the diode. Hence, in reverse-biased operation of the diode, a voltage breakdown at a breakdown voltage U_Z essentially only occurs in the central region of the diode and not in its edge region. To be sure, this results in a high robustness in operation since no avalanche breakdown can occur in the edge region of the diode. It is particularly disadvantageous for applications of the diode at higher voltages, however, that the diode has a comparatively high electrical resistance as a consequence of weakly n-doped layer 1. This resistance causes an undesired voltage drop, which has an adverse effect particularly in breakdown operation. This is all the more pronounced the higher the breakdown voltage U_Z of the diode. For this reason, a conventional diode of this type is not suited for higher breakdown voltages, as are required, for example, for use in vehicle electrical systems that have a 42 V operating voltage. The proposed invention eliminates this disadvantage.

In a schematic sectional view, Figure 2 shows as the first exemplary embodiment of the present invention a semiconductor system 20 made up of multiple sublayers featuring different doping. The starting point is a weakly n-doped semiconductor substrate, which forms a first sublayer 1. In the central region of this semiconductor substrate, a second n-doped sublayer 2, which, however, does not extend to the edge regions of sublayer 1, is introduced from the upper side. Likewise from the upper side, a third p-doped sublayer 3 extends to the n-doped sublayer 2 in the central region and to the n-doped sublayer 1 in the edge region of semiconductor system 20. The boundary regions between sublayers 3 and 2 and between 3 and 1 form the p-n junctions. 5 and 6 designate metallic contact layers that are deposited on the outer surfaces of sublayers 3 and 4. Since the n-doping concentration of sublayer 2 is greater than the n-doping concentration of sublayer 1, the breakdown voltage U_{ZM} of the p-n junction 3-2 lying in the central region of semiconductor system 20 between sublayers 3 and 2 is smaller than the breakdown voltage U_{ZR} of the p-n junction 3-1 lying in the edge region of semiconductor system 20 between sublayers 3 and 1.

This ensures that also in the semiconductor system according to the present invention a breakdown can occur only in the central region of semiconductor system 20 and not in its edge region. As a consequence of the charge neutrality, the space charge region in the edge region of semiconductor system 20 extends further than in its central region. This has the consequence that the electric field strength is reduced at the surface of the edge region of semiconductor system 20. This advantageously results in a lower reverse current and a higher pulse strength. As a consequence of the low reverse current, it is also possible advantageously to dispense with a removal

of the damage zone, for example by an additional etching process. From the backside of semiconductor system 20 a heavily n-doped further sublayer 4 extends out to n-doped sublayer 2 and lightly n-doped sublayer 1. In contrast to the conventional semiconductor system 10 represented in Figure 1, a lightly n-doped sublayer 1 remains only in a narrow edge region between the n-doped sublayers 3 and 4. In the central region of semiconductor system 20, therefore, the n-doping concentration is higher than the basic doping of first sublayer 1 in the semiconductor system. The avoidance according to the present invention of a lightly n-doped sublayer 1 between sublayers 3 and 4 in semiconductor system 20 achieves a significantly lower bulk resistance than in a conventional semiconductor system. In the event of a breakdown, this advantageously results in a lower voltage drop.

A further exemplary embodiment of the semiconductor system of the present invention is represented in a schematic cross-sectional view in Figure 3. In contrast to semiconductor system 20 represented in Figure 2, this semiconductor system 30 has no depression in its edge region. This makes it possible to achieve an even higher breakdown voltage UZR in the edge region of semiconductor system 30 with all the associated advantages such as a lower reverse current and a higher pulse strength, while maintaining the same overall thickness of semiconductor systems 20, 30.

A further exemplary embodiment of the semiconductor system according to the present invention is represented in Figure 6. In contrast to semiconductor systems 20 and 30 in Figure 2 and Figure 3, sublayer 2 is made of the same doping type as sublayer 3.

Furthermore, exemplary embodiments are conceivable in which the starting material of sublayer 1 is not doped homogeneously. Rather, this sublayer 1 is deposited as an epitaxy layer on an already heavily doped sublayer 4.

5 In the following, a particularly advantageous manufacturing method for manufacturing a semiconductor system having the layer structure represented in Figure 2 is described with reference to Figure 2. The manufacture of a diode having a Zener voltage U_Z of approximately 50 volts is described as an
10 example. Of course, using the method according to the present invention, ~~it is also possible to manufacture diodes~~ designed may be provided that are for higher or lower Zener voltages. Thus it is possible, for example, to produce a Zener voltage of approximately 20 volts by a simple variation of the
15 doping profile. One starts from a semiconductor substrate made of silicon having a thickness of approximately 180 μm and an n-doping of approximately $1 \cdot 10^{16} \text{cm}^{-3}$, which forms first sublayer 1 of semiconductor system 20. This sublayer 1 is doped with phosphorus on the upper and lower side. This can be done
20 advantageously using ion implantation, doping glasses, doping foils or, particularly suitably, by a method referred to as the APCVD method (atmospheric pressure chemical vapor deposition). In a particularly simple and economical way, the doping of sublayer 1 by phosphorus atoms can also occur in a
25 gas phase. To this end, sublayer 1 is exposed to an atmosphere of POCl_3 at an elevated temperature. Temperatures approximately between 830°C and 890 °C are suitable for this purpose, particularly a temperature of 870°C. Following the doping process, the glass layers remaining on the semiconductor
30 substrate are removed by an etching process using diluted hydrofluoric acid. If doping glasses are used for doping, then the deposition of the doped glasses is followed by a so-called drive-in step to drive the doping atoms into the semiconductor

substrate to be doped, that is, the first sublayer 1. A drive-in step of 20 to 40 minutes, particularly 30 minutes, has proved to be especially favorable. This drive-in step is suitably performed at an elevated temperature of approximately 1200 to 1300, particularly of 1265 °C. Following this doping step, the integral over the concentration of phosphorus atoms, the dose, amounts on each doped side of first sublayer 1 to approximately $2 \times 10^{16} \text{cm}^{-2}$. The penetration depth of the phosphorus atoms into the n-doped semiconductor material of first sublayer 1 is approximately 5-15 micrometers. In the case of a POCl_3 gas phase deposition it is less than approximately 1 micrometer. Subsequently, the upper side of doped first sublayer 1 is structured. This can occur in a particularly advantageous manner by saw cuts into the upper side using a diamond saw or by water-supported laser cutting. The sawing depth ST (Figure 4) is approximately 1-35 micrometers. As a rule, the sawing depth ST is suitably chosen in such a way that it is greater than the penetration depth of the phosphorus atoms in the surface of sublayer 1. A suitable choice of the sawing depth ST can substantially influence the lateral outdiffusion of the phosphorus layer or the phosphorus concentration and thus the breakdown field strength in the edge region of semiconductor system 20 during the subsequent diffusion process. The width SB of the saw blade used also depends on the desired sawing depth and the subsequent diffusion process. Saw widths SB (Figures 1, 2, 4b, 6) in the order of approximately 300 micrometers are typical. Following this mechanical structuring process, a further diffusion process is performed, in which the n-dopants are driven into the semiconductor substrate. This drive-in ~~process~~ may occur in an oxidizing atmosphere, suitably in dry or also in wet oxygen. As a variation, a diffusion in an atmosphere made of pure nitrogen or a nitrogen-oxygen mixture is possible as well. This diffusion process is also carried

out at a high temperature between 1200 and 1300 °C,
particularly at a temperature of 1265 °C. The semiconductor
substrate is exposed to this temperature for approximately 140
hours. During the diffusion process, the semiconductor
5 substrate is positioned on a suitable carrier, which ~~is~~
~~preferably~~may be made of SiC or a similar temperature-
resistant material. Following the previously described
diffusion process, the layer of SiO₂ thereby produced on the
surface of the semiconductor substrate is etched off again. In
10 order to increase the efficiency of the method, in principle
multiple semiconductor substrates can be piled into a stack
and be jointly exposed to the diffusion process. For this
purpose, so-called neutral foils (neutral preforms) are
suitably arranged between the individual semiconductor
15 substrates. These neutral foils contain antitack agents such
as pellets made of SiC or Al₂O₃ for example and thus prevent
the semiconductor substrates from sticking together. Following
a successful conclusion of the diffusion process, the
individual semiconductor substrates are again separated from
20 one another using diluted hydrofluoric acid. In a subsequent
further diffusion process, an additional sublayer 3 is now
applied which is p-doped. At the same time, the concentration
of the doping atoms in sublayer 4 is to be increased further.
In principle, all doping methods familiar to one skilled in
25 the art are suited for this purpose. The use of so-called
doping foils, however, is particularly advantageous. For this
purpose, alternately p-doping foils and n-doping foils
together with the semiconductor substrates are again piled up
into stacks and heated together. This process step requires a
30 time of approximately 30 hours at a temperature of 1265 °C.
Especially advantageous in this implementation of the method
is the fact that sublayers 3 and 4 can be produced together in
one single diffusion step. As already described above,
following the conclusion of the diffusion step, the individual

semiconductor substrates are again separated from one another using diluted hydrofluoric acid.

The diffusion profile in the central region (compare step AB in Figure 2) of a diode manufactured in the previously

5 described manner is represented in the diagram in Figure 5 (curve shape II). This diagram shows the doping concentration as a function of the distance x . As a special feature it may be pointed out that the minimum doping concentration in this diode is greater than the basic doping of the semiconductor
10 substrate, that is, the doping of first sublayer 1 in Figure 2 or 3.

In contrast to the conventional structure of a semiconductor system according to Figure 1, in which the sawing-in process only occurs after the diffusion of n-doped sublayer 2, in the
15 ~~design approach according to the exemplary embodiment and/or exemplary method of~~ the present invention a smaller sawing depth ST can be chosen than in the conventional semiconductor system. Since the portion of first sublayer 1 still remaining is greater than in the conventional design approach, it is
20 possible to achieve higher breakdown voltages UZR in the edge region of the semiconductor structure according to the present invention. If, as in the conventional semiconductor structure, it is not possible to select a sawing depth that is
sufficiently small because the sawing-in process occurs only
25 after the first diffusion treatment of n-doped sublayer 2, p-doped third sublayer 3 diffuses together with n-doped sublayer 4 in the edge region of the semiconductor system. This, however, greatly reduces the breakdown voltage UZR.

In a further ~~alternative embodiment of the exemplary~~ method
30 according to the present invention, the previously described joint diffusion of p-doped sublayer 3 and n-doped sublayer 4 can also be split up into two partial steps. To this end, the

dopants are initially introduced in the first partial step and are then driven in further in a second partial step. Again, the doping and diffusion methods already described above can be used for this purpose. In particular, it is possible to use stack diffusion and diffusion in boots or a combination of both methods.

Subsequently, the upper side and the lower side of the semiconductor substrate are each provided with one contact layer 5, 6 made of metal (Figure 2). Preferably,

~~however~~However, a complex layer sequence made of several metals ~~is~~may be deposited for this purpose. The combination chromium, nickel, silver, for example, is particularly well suited.

Following the metallization of the contact regions of the semiconductor substrates, the individual semiconductor systems, that is, diodes in the exemplary embodiment described, are separated from one another for example by sawing using a diamond saw. Customarily, saw blades of a width of 40 micrometers are used for this purpose. This sawing process yields individual diodes, which are normally additionally equipped with a housing. The diode is soldered into the housing and is protected by it.

In unfavorable sawing condition that depend, for example, on the grain size of the diamond splinters of the saw, the rotational speed and the feed rate, the separation of the semiconductor substrates with the aid of a diamond saw can cause faulty crystal zones in the edge region of semiconductor system 20, 30, 60. These faulty crystal zones in turn give rise to undesired additional reverse currents in the operation of the semiconductor system. Thus the faulty crystal zones are normally removed in an additional method step, by etching for example. In semiconductor system 20, 30, 60 according to the

exemplary embodiment and/or exemplary method of the present
invention, however, breakdown voltage UZR in the edge region
of the semiconductor system is significantly higher than in a
conventional semiconductor system such as the one according to
5 Figure 1. Hence the ratio of the breakdown voltage UZR at the
edge region of semiconductor system to the breakdown voltage
UZM in the central region of the semiconductor system is also
significantly higher. This has the consequence that in the
semiconductor system configured according to the present
10 invention, the reverse current originating from the possibly
faulty edge region is significantly lower.

Thus in most cases it is also not necessary to remove the
faulty crystal zones (damage zones) in the edge region of the
semiconductor system according to the present invention. This
15 results in a simplification of the manufacturing method and
thus to an additional reduction in cost.

If the faulty edge regions are removed nevertheless, as is
described in the following, a yet significantly lower reverse
current is achieved. Wet-chemical etching methods using KOH,
20 gas phase etching or similar methods lend themselves for
removing the faulty edge regions of the semiconductor system.
However, since in contrast to conventional semiconductor
systems only very shallow sawing trenches are required, a wet-
chemical etching method using KOH or a comparable etching
25 solution lends itself especially well. In a conventional
semiconductor system according to Figure 1, the required
sawing trench is particularly deep and narrow. For example,
the ratio of sawing width SB to sawing depth ST is 2.5. In
semiconductor system 20 according the present invention as
30 shown in Figure 2, by contrast, the ratio of sawing width SB
to sawing depth ST is 15 for example. These ratios are
represented in Figure 4 by partial figures Figure 4a and
Figure 4b. In both figures, an enlarged detail of an edge

region of a semiconductor system is shown in cross section. The semiconductor substrate is identified by 7. Reference numeral 8 designates a solder layer. Reference numeral 9 indicates a heat sink made of copper for example. The sawing width is indicated by the letter combination SB and the sawing depth by ST.

A conventional semiconductor system is represented in Figure 4a, while Figure 4b shows a semiconductor system according to the present invention. As figure 4b clearly shows, in the semiconductor system according to the present invention, solder layer 8 completely fills the sawing trench indicated by sawing width SB and sawing depth ST. This has the advantage that in a subsequent wet-chemical etching process contact layer 5 or the semiconductor material below it are no longer attacked in the region of the sawing trench since they are completely covered by solder layer 8. Moreover, a sawing trench filled completely with ductile solder material offers the advantage that the semiconductor substrate is relieved mechanically if as a result of temperature change stresses, pressure and/or shearing forces are exerted on the semiconductor system. In addition, the dissipation of heat from the semiconductor substrate is further improved. The advantages described above, by contrast, cannot be obtained with the embodiment of a conventional semiconductor system shown in Figure 4a.

A further exemplary embodiment of a semiconductor system according to the present invention is represented schematically in Figure 3 in cross section. In this case, a depression of the semiconductor substrate in the edge region was dispensed with completely. This allows for an even higher breakdown voltage UZR in the edge region, while maintaining the same thickness of the semiconductor substrate as in semiconductor system 20 in Figure 2. This results in further

advantages such as a lower reverse current and a greater pulse strength. The structural design and the manufacturing method are practically identical as in the exemplary embodiment of the present invention described above with reference to Figure 2. The structuring of n-doped layer 2, however, may also occur advantageously by method steps known from conventional photolithography and planar technology. These method steps include in particular the steps of thermal oxidation, photo-resist coating, pre-curing, exposure and curing of the photo-resist, etching of the contact windows and stripping of the photo-resist. In sufficiently thick thermal oxide layers, the oxide layer may advantageously also act as a diffusion barrier for the phosphorus atoms to be introduced into the semiconductor substrate. In the high diffusion temperatures used, the oxide layer must have a thickness of 3-5 micrometers. The structuring occurs in such a way that in the central region of the semiconductor substrate no oxide layer remains, while at its edge R, however, an oxide layer does remain. This structuring step is followed by the process steps already described above, beginning with the doping of n-doped layer 2.

A further exemplary embodiment of a semiconductor system according to the present invention is represented schematically in a cross section in Figure 6. Deviating from the exemplary embodiment of semiconductor system 20 in Figure 2, sublayer 2 is doped with boron instead of phosphorus. In contrast to semiconductor system 20, reverse current U_{ZM} at the center of the semiconductor system is determined by the junction between sublayers 2-4 and not by the junction between sublayers 3-2.

In principle, exemplary embodiments are possible as well in which starting material 1 is not available in homogeneously

doped form but rather as an epitaxy layer that is deposited on an already heavily doped substrate 4.

Even if semiconductor diodes, particularly Zener diodes, are represented in the figures, the ~~teaching~~disclosure according to the exemplary embodiment and/or exemplary method of the present invention can also be applied to other semiconductor systems which have a p-n junction between a heavily doped p-layer and a heavily doped n-layer followed by a more weakly doped n-layer. Likewise semiconductor components are possible in which all p-layers and n-layers are interchanged.

The List of Reference Characters is as follows:

	1	Doped layer
	2	Doped layer
	3	Doped layer
5	4	Doped layer
	5	Contact layer
	6	Contact layer
	7	Semiconductor substrate
	8	Solder layer
10	9	Heat sink
	10	Semiconductor system
	20	Semiconductor system
	30	Semiconductor system
	60	Semiconductor system
15	SB	Sawing width
	ST	Sawing depth
	R	Edge

~~Abstract~~ABSTRACT OF THE DISCLOSURE

In a semiconductor system 20 made up of multiple sublayers~~1,~~
~~2, 3, 4,~~1 a sublayer~~4~~ over the largest part of a cross-
sectional area BC in the interior of the semiconductor system
5 ~~20~~ borders immediately on the first sublayer~~2,~~1 while
bordering on a second sublayer ~~1~~ only in a comparatively
narrow edge region of the cross-sectional area~~BC~~. The
semiconductor system is characterized by a low bulk resistance
and a high breakdown voltage in the edge region. In addition,
10 a method for manufacturing this semiconductor system is
specified.

~~(Figure 2)~~